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(54) COMPOSITE TUBULAR MEMBER WITH MULTIPLE CELLS

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TUBE COMPOSITE A CELLULES MULTIPLES

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Description

[0001] Coiled steel tubing finds a number of uses in oil well operations. For example, it is used in running wireline cable down hole with well tools, such as logging tools and perforating tools. Such tubing is also used in the workover of wells, to deliver various chemicals.

[0002] Steel coiled tubing is capable of being spooled because the steel used in the product exhibits high ductility (i.e. the ability to plastically deform without failure). The spooling operation is commonly conducted while the tube is under high internal pressure which introduces combined load effects. Unfortunately, repeated spooling and use causes fatigue damage and the steel coiled tubing can suddenly fracture and fail. The hazards of the operation and the high personal and economic cost of failure in down time in fishing operations forces the product to be retired after relatively few trips into a well. The cross section of steel tubing expands during repeated use, causes reduced wall thickness and results in lower pressure allowables and higher bending strains.

[0003] It is desirable to provide a non-steel coil tubing which is capable of being spooled and which does not suffer from the defects of steel tubing.

The Prior Art

[0004] U.S. Patent No. 3,554,284 to Nystrom teaches the use of a logging cable in which two inner layers of fibers are wound at ±18° and two outer layers are wound at ±35°.

[0005] U.S. Patent No. 4,255,820 to Rothermel et al. discloses a prosthetic ligament formed with a densely woven cylindrical core that provides the axial stiffness for the prosthesis.

[0006] U.S. Patent No. 4,530,379 to Policelli teaches a composite fiber tubing with a transition to a metallic connector. The fibers may be graphite, carbon, aramid or glass. These fibers, in one embodiment, are alternatively laid in ±15° orientations to the longitudinal axis. In the Fig. 4 embodiment, "a wider choice of axial angles of filaments in the layers" is permitted. Further, "This embodiment can be employed in a fluid conveyance pipe having bending loads in addition to internal pressure loads and in structural members having bending and axial stiffness requirements". Policelli suggests that the fiber angles can be selected in a range between 5° and 75° as measured from the axis.

[0007] U.S. Patent No. 4,728,224 to Salama discloses a composite mooring tendon on interspersed layers of carbon fibers and aramid fibers, the fibers being axial or low angle helical wrap. A layer of 90° wrap fibers can be provided as an external jacket.

[0008] FR-A-617257 describes a hose for use in fire fighting. The hose is formed from a combination of rubber and spiral-wound woven fabric, and has two separate internal passages. These allow different liquids to flow to a nozzle where they are mixed together.

[0009] According to the present invention there is provided a composite tubular member adapted for being spooled and unspooled from a reel comprising an outer composite generally cylindrical member containing fibers oriented to resist internal pressure, an inner composite member forming a web member extending through the longitudinal axis of the composite tubular member to form a major and minor moment of inertia and thus a preferred direction of bending about the minor moment of inertia, said inner composite member connecting between opposite walls of said composite outer generally cylindrical member to form at least two separate cells between said web member and said outer generally cylindrical member, characterised in that said outer member contains fibers cross-plied and oriented at about ± 40° to ± 70° to the axis of the tubular member to provide low bending stiffness, in that the web member contains fibers oriented at approximately ±40 to ±60° to resist shear stress and in that said inner composite member contains fibers oriented at approximately 0° to the axis of the tubular member to provide high stiffness in the axial direction, high tensile strength and low bending stiffness about the minor moment of inertia.

[0010] Preferably, the composite tubular member is suitable for use in well logging and workover operations in oil wells.

Brief Description of the Drawings

[0011] Figure 1 is a schematic cross-sectional view of a composite tubular member containing four cells of equal cross-section.

[0012] Figure 2 is a graph showing reductions in the ratio of the strain as a function of increasing the cross-ply angle for a laminate made of high strength graphite fiber.

[0013] Figure 3 is a schematic cross-sectional view of a composite tubular member having two separate opposing cells.

[0014] Figure 4 is a schematic cross-sectional view of a composite tubular member having two separate opposing cells in which the composite web members and the solid core member are combined in a single web member of uniform cross-section extending through the axis of the composite tubular member.

[0015] Figure 5 is a schematic cross-sectional view of a composite tubular member showing the internal arrangement of fibers of differing angularities.

[0016] Figure 6 is a schematic cross-sectional view of the solid core of a composite tubular member showing an alternative internal arrangement of the fibers.

[0017] Figure 7 is a schematic cross-sectional view of another composite tubular member showing the internal fiber arrangement.

Detailed Description of the Invention

[0018] Composite fibers (graphite, Kevlar®, fiberglass, boron, etc.) have numerous assets including high strength, high stiffness, light weight, etc., however, the stress-strain response of composite fibers is approximately linear to failure and therefore non ductile. Composite coiled tubing must therefore address the strain limitations in another manner, i.e., by providing a design to meet the requirements with a near elastic response.

[0019] Such a composite design must have high resistance to bending stresses and internal pressure. It must also have high axial stiffness, high tensile strength and be resistant to shear stress. All of these properties are combined in the composite tubular member of the invention to provide a coiled tubing which can be bent to a radius compatible with a reasonable size spool.

[0020] The invention is best described by reference to the drawings. Figure 1 shows a cross-sectional view of a composite tubular member which is made up of a composite cylindrical member 8, a composite inner core member 2 and four composite web members 6 which connect inner core member 2 with composite cylindrical member 8 to form four equal cells 7. Composite cylindrical member 8 contains fibers which are cross-plied and oriented at ±55° to the axis of the tubular member. The (±) signifies opposite orientation of the fibers at the degrees indicated. This orientation of the fibers is the optimum to achieve maximum structurally efficiency for outer cylindrical member 8 when such member is subjected to bending and is under internal pressure loading. Outer cylindrical member 8 will usually contain from about 5 to about 10 percent fibers which are oriented at approximately 90°, that is, approximately perpendicular to the axis of the composite tubular member. The inclusion of the 90° fibers lowers the Poisson's ratio of the composite tubular member toward 0.5 and carries the shear stress during bending to better resist delamination in such member.

[0021] The inner core member 2 which is centrally located in the composite tubular member contains fibers which are oriented at 0° to the axis of the tubular member to meet the requirement for high axial stiffness and high tensile strength and are so located to permit the composite tubular member to exhibit a low bending stiffness. Concentrating the high axial stiffness portion of the composite tubular member at the center of the cross-section minimizes the axial strain in the fibers during bending. Axial loading and thermal expansion may cause shear and transverse stresses, which may cause cracks in core member 2, therefore it is desirable to provide in this member, some fibers which are cross-plied and oriented at ±45° to the axis of the tubular member to provide resistance to delamination. The ±45° oriented material which may be provided either in the form of a unidirectional or woven fabric or braided material is usually present in inner core 2 in an amount between about 5 and about 25 percent.

[0022] Composite web members 6 contain fibers oriented at ±45° to the axis of the tubular member. The web is a region of high shear and a ±45° orientation of the fibers is the optimum angle ply to resist shear loading.

[0023] The fibers contained in the outer cylindrical member, the centrally located core member and the web members are held together with a plastic binder such as vinyl ester. epoxy, or a thermoplastic or thermosetting resin.

[0024] Economic, structural, damage tolerance and manufacturing considerations may make it advantageous to use fibers of different materials and different resins for the three components of the composite tubular member. For example, the high stiffness and high strength core requirements of the central core member may best be met by using 0° graphite fibers. On the other hand, lower cost and higher strain to failure of glass fibers may make fiber glass the material of choice for the outer cylindrical member and the web members. Other fibers which also may be used are ceramic fibers, polymer fibers, for example, from Kevlar® polymer which is a product of the Du Pont Company and from Exten® polymer which is product of The Goodyear Corporation. The plastic binders mentioned, among others may be used in the preparation of the components of the composite tubular member from these materials.

[0025] The size of the various components in the composite tubular member will depend on the size of this member. If the composite tubular member is used as coiled tubing, it will usually have a diameter of not more than about 5,08 cm (2 inches). The outer composite cylindrical member in a coiled tubing will have a thickness of between about 3,81 mm (0.15) and about 10,16 mm (0.40 inches). The inner core member of such coiled tubing will have a diameter of between about 5,08 mm (0.2) and about 12,7 mm (0.5 inches) and the web members will be between about 2,54 mm (0.10) and about 6,35 mm (0.25 inches) thick.

[0026] Referring again to Figure 1, it may be desirable to line the interior of each of cells 7 with an abrasion and chemically resistant material 4 to provide a pressure tight chamber. Materials such as Rilsan® which is sold by ATO Chem, Teflon®, Kevlar®, Nylon, and Hytrel®, sold by Du Pont, or Kevlar® frit may be used for this purpose.

[0027] In service, the composite tubular member may buckle and at the points of buckling, impose a normal force on the walls of the casing or open hole. This force will create friction as the tubular member is moved down the hole. The exterior of the composite tubular member may be covered with a protective abrasion resistant cover 10 to resist such wear and friction. Here again, materials such as Kevlar®, Teflon®, Nylon, Rilsan®, Hytrel®, or Kevlar® frit may be used to form this protective covering.

[0028] The axial strain in the fiber due to bending in both the outer cylindrical member and the web members

of the composite tubular member is significantly lower than would be similarly placed 0° oriented fibers. Typical reductions in the ratio of fiber strain to the imposed axial strain for a moss-plied laminate presented as a function of the cross-ply angle are presented in the graph of Figure 2 using representative properties of a high strength graphite fiber. It is noted that for angles greater than approximately ±25° the fiber strain is less than half the axial strain imposed on the laminate and rapidly reduces for larger cross-ply angles. Orienting the fibers in the outer cylindrical member and in the web members in the manner described herein, optimizes the ability of the composite tubular member to carry the imposed set of loads and minimizes the bending strain in the fibers. Minimizing the bending strain in the fibers permits larger diameters for the outer cylindrical member portion of the composite tubular member than would be otherwise possible for a specific diameter spool. Conversely a given diameter composite tubular member so tailored, can be wound onto a smaller diameter spool. The cylindrical shape of the composite tubular member is also well suited for introducing such member into the well with the belt drive mechanism which is normally used to force the tubular member downhole.

[0029] The subdivision of the composite tubular member into cells has additional utility for workover and logging operations. Individual cells can be used for transporting different fluids downhole, for controlled circulation (down one cell and up another), and for ducts for channeling electrical and other communication lines downhole. The four cell configuration shown in Figure 1 provides rigid, structural continuity between the solid core and the composite cylindrical outer member. Under extreme bending, the composite tubular member may experience a so-called brazier flattening effect which serves to help relieve bending strains.

[0030] Fewer or larger numbers of cells may be used in the cross-section of the composite tubular member. It is possible, for example, to use only two cells. Such a configuration is shown in Figure 3. In this Figure, the outer composite cylindrical member 18 is joined to the centrally located core member 12 by web members 16 to form two opposing cells 19. The cells are lined with an abrasive, chemically resistant material 14 and the exterior of the composite tubular member is protected by an abrasion resistant cover 20.

[0031] One advantage of the composite tubular member shown in Figure 3 is that the core containing the 0° oriented fibers will assume large displacement away from the center of the cross-section of the composite tubular member during bending along with tube flattening to achieve a minimum energy state. This deformation state has the beneficial result of lowering critical bending strains in the tube. The secondary reduction in strain will also occur in composite tubular members containing a larger number of cells, but is most pronounced for the two cell configuration.

[0032] A variation in design in the two cell configuration is shown in Figure 4 in which the 0° material 22 is widened to provide a plate-like core which extends out to the outer cylindrical member 24. In effect, the central core member and the web members are combined to form a single web member of uniform cross-section extending through the axis of the composite tubular member.

[0033] The material tailoring of this invention creates a major and minor moment of inertia and forces a preferred direction of bending. In effect, this forces the composite tubular member to wind onto a spool by bending about the minor moment of inertia. Downhole, the buckle pattern will be a mixed mode having one period associated with the minor moment of inertia and a longer, smaller curvature mode associated with the major moment of inertia. The advantage of this configuration is that more high stiffness and high strength material can be placed in the core without significant increase in the associated bending strains or sacrifice in the minimum radius curvature permitted for spooling.

[0034] In Figures 5, 6, and 7, the broken lines within the bodies of the tubulars indicate the orientation of the fibers in a layer of the tubular. In particular, the dotted lines indicate fibers oriented approximately 0° to the axis of the tubular. Unes formed by alternating dots and dashes indicate fibers oriented approximately ±40° to ±60° to the axis of the tubular. Unes comprised of long dashes separated by two short dashes indicate fibers oriented approximately ±40° to ±70° to the axis of the tubular. Finally, a purely dashed line indicates fibers oriented approximately 90° to the axis of the tubular. Figure 5 illustrates the internal arrangement of the fibers for a composite tubular member such as that shown in Figure 3. Referring to Figure 5, the angularity of the various fibers in the composite tubular member is represented by single lines as is shown in the legend. Each line represents a number of fiber thicknesses or a number of fiber plies. In Figure 5, 32 designates the outer abrasive cover, and 30 the inner abrasion and chemically resistant liner for the cells. As shown in the drawing, the central inner core is made up of 0° oriented material and ±45° cross-plied material arranged in a circular configuration. The cross-plied fibers are usually provided in a woven fabric or braided material which as shown, may be extended from the core member to form the web members joining the core member and the outer cylindrical member of the composite tubular member. For structural continuity and sealing at least part of the ±45° web material is continued around the inner portion of the outer cylindrical member to form an enclosed cell. The 0° oriented fiber may also be provided in cloth or fabric form, however, this material is usually present as rovings, i.e. bundles of fibers. Stress concentration may occur in areas where the ±45° fibers in the central core member and the web members make bends that separate the fabric containing these fibers. Concentrations of 0' fibers in these areas, e.g., in the form of rods 34, will provide a local radius and alleviate such stresses.

Rods 34 may be formed of a different fiber material than the 0° material contained in the central inner core. As pointed out previously, the outer composite cylindrical member contains primarily ±55° cross-plied fibers with a small amount of approximately 90° oriented fibers. The fibers in the various elements of the composite tubular member are held together or laminated with a suitable plastic binder (previously described) which is not shown in the drawing.

[0035] Figure 6 shows an alternative arrangement of the 0° and ±45° fibers in the inner core of the composite tubular member. While the inner core member has been shown in the Figures as a circular member, it also may be oval shaped. Making the inner core member oval shaped places the material in the core closer to the neutral axis.

[0036] Figure 7 shows the internal arrangement of the fibers for a composite tubular member like that shown in Figure 4. As in Figure 6, the fibers of different angularity are represented by the different lines shown in the legend. In Figure 7, 38 represents the outer abrasion resistant cover covering material for the composite tubular member and 36 represents the liner for the cells in the composite tubular member. The thick web which divides the composite tubular member into two opposing cells is again made up of 0° oriented fibers and ±45° fibers. As in Figure 5, structural continuity and sealing is obtained by continuing at least part of the ±45° web material around the outside of each cell.

[0037] The ±45° fibers which are utilized in the web members and in part in the central core member are of the preferred orientation. However, it is possible to use fibers oriented from ±40° to ±60° in these members. The fibers which are used in the outer composite cylindrical member may vary in orientation from ±40° to ±70° although the ±55° orientation, as previously pointed out, is preferred for some design requirements.

[0038] The fiber sequence or stacking sequence of the ±55°, 0°, 90° and ±45° fiber orientations shown in the drawings is only representative and may be varied to meet specific design requirements.

[0039] In addition to its use in well logging and well workovers, the composite tubular members of the invention may be used in subsea hydraulic lines or as production tubing in which long sections of tubing are spooled and run downhole for permanent production. One advantage of cells in production tubing is for dual completion wells. Production tubing is normally larger in diameter than is required of coiled tubing and may for onshore use become too large to bend onto a practical diameter spool. If tubing diameters become too large for spooling, it is entirely feasible to manufacture the composite tubular members on site, on shore or offshore. Larger spool sizes are practical offshore where the composite tubular member can be manufactured near a dock site.

[0040] Another benefit may be noted for using composite coiled tubular members. With composite coiled tubing, deformations are totally elastic and this stored energy can be constructively used to help free the tubing from a stuck position or high friction bind. The pressure in the tubing can be pulsed to provide the foreseen function. Although this technique may have merit for steel coiled tubing as well as composite coiled tubing, the high stiffness of steel compared to the lower stiffness of the tubular members of this invention limits the magnitude of the local displacements associated with pressure pulsing steel tubing compared to displacements imposed using composite tubing. Activating a seal in the tubing down hole will permit pressure pulsing the composite tubing with a lower pressure imposed on the inside and the outside of the tubing. Pressure pulsing can also aid in freeing the coiled composite tubing stuck downhole.

[0041] In forming composite structures, several well known techniques may be used such as pultrusion, filament winding, braiding and molding. In pultrusion, filaments or fibers are drawn through a resin impregnating apparatus, then through dies to provide the desired shapes. Alternatively, the resin may be injected directly within the die. Heat forming and curing means are provided in conjunction with the dies. Finally, the desired product which is produced continuously may be wound onto a reel or spool. As an example, pultrusion is used in U.S. Patent 4,416,329 to prepare a ribbon structure containing bundles of graphite fibers saturated with thermoplastic resin. The faces of the ribbon are covered with plies of woven material, such as glass fabric. Corner tows on the ribbon are made of Kevlar® or glass. U.S. Patent 4,452,314 uses pultrusion to form arcuate sections comprised of glass filaments or other reinforcing material disposed in a thermosetting resin. The arcuate sections are combined to form a sucker rod.

[0042] While any of the known fabrication techniques may be used, pultrusion or pultrusion in combination with braiding or filament winding is the preferred procedure for preparing the composite tubular member of the invention. This procedure is particularly applicable since it enables the composite tubular member to be produced as a continuous product to whatever length is desired. The pultrusion process may utilize material which is prepared by weaving or braiding the fibers. Woven or braided material can be prepared as feed stock or can be fabricated on-line as a part of the pultrusion operation. Pull winding in which some of the material is wound onto the part in advance of the pultrusion dies is another appropriate manufacturing process.

[0043] When the composite tubular member is prepared by pultrusion it may be desirable to add some 0° oriented fiber to the outer composite cylindrical member, up to about 10 percent, to aid in the manufacturing process.

Claims

1. A composite tubular member adapted for being spooled and unspooled from a reel comprising an outer composite generally cylindrical member (8,18) containing fibers oriented to resist internal pressure, an inner composite member forming a web member extending through the longitudinal axis of the composite tubular member to form a major and minor moment of inertia and thus a preferred direction of bending about the minor moment of inertia, said inner composite member connecting between opposite walls of said composite outer generally cylindrical member (8,18) to form at least two separate cells (7,19) between said web member (6,16) and said outer generally cylindrical member (8,18), characterised in that said outer member (8,18) contains fibers cross-plied and oriented at about ± 40° to ± 70° to the axis of the tubular member to provide low bending stiffness, in that the web member contains fibers oriented at approximately ±40° to ±60° to resist shear stress and in that said inner composite member (6,16) contains fibers oriented at approximately 0° to the axis of the tubular member to provide high stiffness in the axial direction, high tensile strength and low bending stiffness about the minor moment of inertia.

2. A tubular member as claimed in claim 1 in which there are two oppositely disposed composite web members forming separate cells of equal cross-section in said tubular member.

3. A tubular member as claimed in claim 1 or 2, in which said web member includes an inner central composite member to form a single web member extending through the longitudinal axis of said tubular member.

4. A tubular member as claimed in any preceding claim, in which there are four oppositely disposed composite web members (6) forming four separate cells (7) of equal cross-section in said tubular member.

5. A tubular member as claimed in any preceding claim, in which the outer composite generally cylindrical member (8,18) contains from about 5 to about 10 percent fibers oriented approximately 90° to the axis of the tubular member.

6. A tubular member as claimed in any preceding claim, in which the inner composite member (6,16) contains from about 5 to about 25 percent fibers oriented ±40° to ±60° to the axis of the tubular member.

7. A tubular member as claimed in any preceding claim, in which the inner surface of the cells are lined with an abrasion resistant impermeable material (36) and the outer surface of the tubular member is covered with a material (38) resistant to abrasion and having a low coefficient of friction.

Patentansprüche

1. Verbundmaterial-Rohrelement, das dazu geeignet ist, von einer Rolle aufgewickelt und abgewickelt zu werden, umfassend ein äußeres im allgemeinen zylindrisches Verbundmaterial-Element (8, 18), welches Fasern enthält, die derart orientiert sind, daß sie innerem Druck standhalten, ein inneres Verbundmaterial-Element, welches ein Stegelement bildet, das sich durch die Längsachse des Verbundmaterial-Rohrelements erstreckt, um ein größeres und ein kleineres Trägheitsmoment und somit eine bevorzugte Biegerichtung um das kleinere Trägheitsmoment zu bilden, wobei das innere Verbundmaterial-Element entgegengesetzte Wände des im allgemeinen zylindrischen äußeren Verbundmaterial-Elements (8, 18) verbindet, um wenigstens zwei getrennte Zellen (7, 19) zwischen dem Stegelement (6, 16) und dem im allgemeinen zylindrischen äußeren Element (8, 18) zu bilden,
dadurch gekennzeichnet, daß das äußere Element (8, 18) zum Bewirken geringer Biegesteifigkeit quer gefachte und unter ca. +/- 40° bis +/- 70° gegen die Achse des Rohrelements orientierte Fasern enthält, daß das Stegelement unter ca. +/- 40° bis +/- 60° orientierte Fasern enthält, um Scherbeanspruchung standzuhalten, und daß das innere Verbundmaterial-Element (6, 16) Fasern enthält, die unter ca. 0° gegen die Achse des Rohrelements orientiert sind, um hohe Steifigkeit in der axialen Richtung, hohe Zugfestigkeit und niedrige Biegesteifigkeit um das kleinere Trägheitsmoment zu bewirken.

2. Rohrelement nach Anspruch 1, in welchem zwei entgegengesetzt angeordnete Verbundmaterial-Stegelemente vorgesehen sind, die in dem Rohrelement getrennte Zellen mit gleichem Querschnitt bilden.

3. Rohrelement nach Anspruch 1 oder 2, in welchem das Stegelement ein inneres zentrales Verbundmaterial-Element enthält, um ein einziges Stegelement zu bilden, das sich durch die Längsachse des Rohrelements erstreckt.

4. Rohrelement nach einem der vorhergehenden Ansprüche, in welchem vier entgegengesetzt angeordnete Verbundmaterial-Stegelemente (6) vorgesehen sind, die in dem Rohrelement vier getrennte Zellen (7) mit gleichem Querschnitt bilden.

5. Rohrelement nach einem der vorhergehenden Ansprüche, in welchem das im allgemeinen zylindrische äußere Verbundmaterial-Element (8, 18) zwischen ca. 5 und ca. 10 % Fasern enthält, die unter ungefähr 90° gegen die Achse des Rohrelements orientiert sind.

6. Rohrelement nach einem der vorhergehenden Ansprüche, in welchem das innere Verbundmaterial-Element (6, 16) von ca. 5 bis ca. 25 % Fasern enthält, die +/- 40° bis +/- 60° gegen die Achse des Rohrelements orientiert sind.

7. Rohrelement nach einem der vorhergehenden Ansprüche, in welchem die innere Oberfläche der Zellen mit einem verschleißfesten, undurchlässigen Material (36) ausgekleidet ist und die äußere Oberfläche des Rohrelements mit einem verschleißfesten Material (38) mit niedrigem Reibungskoeffizient bedeckt ist.

Revendications

1. Organe tubulaire composite adapté pour être bobiné et débobiné d'une bobine comprenant un organe extérieur composite de forme générale cylindrique (8, 18) contenant des fibres orientées pour résister à une pression interne, un organe intérieur composite formant une âme s'étendant au travers de l'axe longitudinal de l'organe tubulaire composite pour former des moments majeur et mineur d'inertie et ainsi une direction préférée de flexion autour du moment mineur d'inertie, ledit organe intérieur composite reliant des parois opposées dudit organe extérieur composite de forme générale cylindrique (8, 18) pour former au moins deux alvéoles séparées (7, 19) entre ladite âme (6, 16) et ledit organe extérieur de forme générale cylindrique (8, 18), caractérisé en ce que ledit organe extérieur (8, 18) contient des fibres diagonales et orientées entre environ ±40° et ±70° par rapport à l'axe de l'organe tubulaire pour fournir une faible rigidité à la flexion, en ce que l'âme contient des fibres orientées d'environ ±40° à ±60° pour résister à une contrainte de cisaillement, et en ce que ledit organe intérieur composite (6, 16) contient des fibres orientées à environ 0° par rapport à l'axe de l'organe tubulaire pour fournir une forte rigidité selon la direction axiale, une haute résistance à la traction et une faible rigidité à la flexion autour du moment mineur d'inertie.

2. Organe tubulaire selon la revendication 1, dans lequel sont prévus deux âmes composites disposées de manière opposée et formant des alvéoles séparées de section transversale égale dans ledit organe tubulaire.

3. Organe tubulaire selon la revendication 1 ou 2, dans lequel ladite âme comprend un organe intérieur central composite pour former une âme unique s'étendant au travers de l'axe longitudinal dudit organe tubulaire.

4. Organe tubulaire selon l'une quelconque des revendications précédentes, dans lequel sont prévues quatre âmes composites (6) disposées de manière opposée et formant quatre alvéoles séparées (7) de section transversale égale dans ledit organe tubulaire.

5. Organe tubulaire selon l'une quelconque des revendications précédentes, dans lequel l'organe extérieur composite de forme générale cylindrique (8, 18) contient d'environ 5 à environ 10% de fibres orientées approximativement à 90° par rapport à l'axe de l'organe tubulaire.

6. Organe tubulaire selon l'une quelconque des revendications précédentes, dans lequel l'organe intérieur composite (6, 16) contient d'environ 5 à environ 25% de fibres orientées de ±40° à ±60° par rapport à l'axe de l'organe tubulaire.

7. Organe tubulaire selon l'une quelconque des revendications précédentes, dans lequel les surfaces intérieures des alvéoles sont revêtues avec un matériau imperméable résistant à l'abrasion (36) et la surface extérieure de l'organe tubulaire est recouverte avec un matériau (38) résistant à l'abrasion et ayant un faible coefficient de friction.

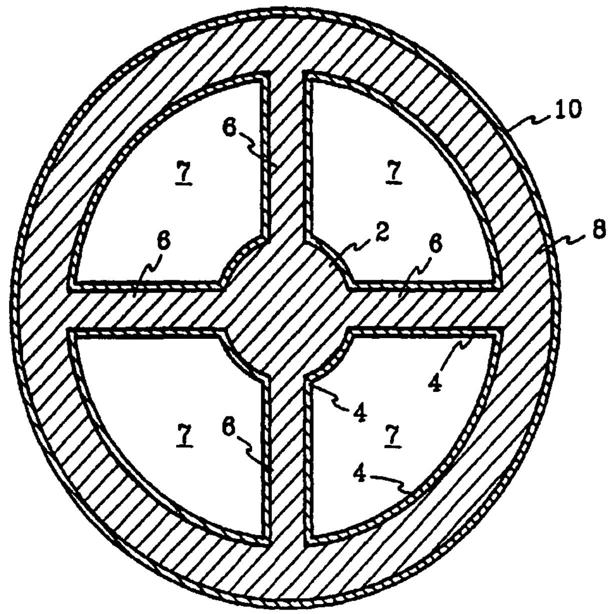

Fig. 1

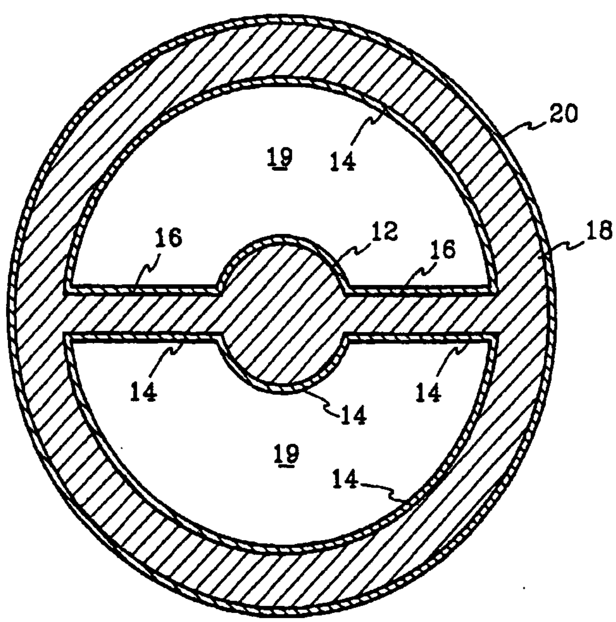

Fig. 3

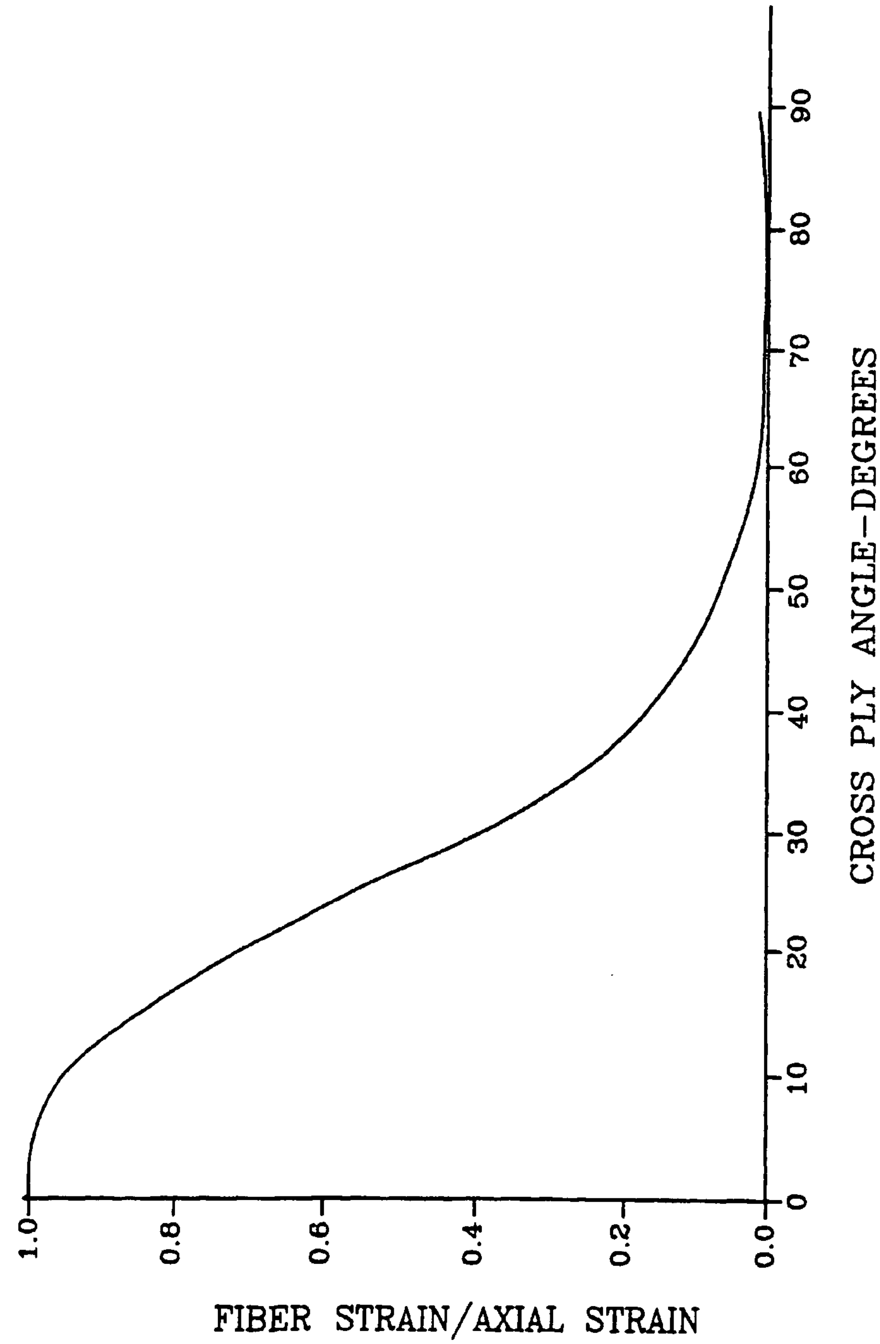
FIBER STRAIN/AXIAL STRAIN
1.0
0.8
0.6
0.4
0.2
0.0
CROSS PLY ANGLE-DEGREES
0
10
20
30
40
50
60
70
80
90

Fig. 2

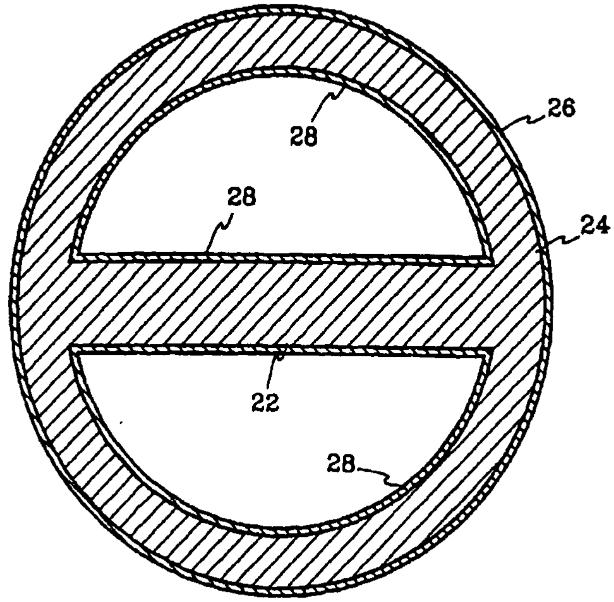

Fig. 4

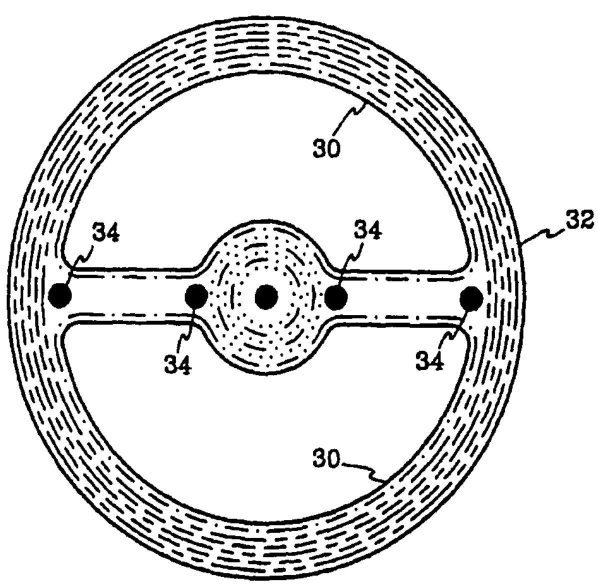

Fig. 5

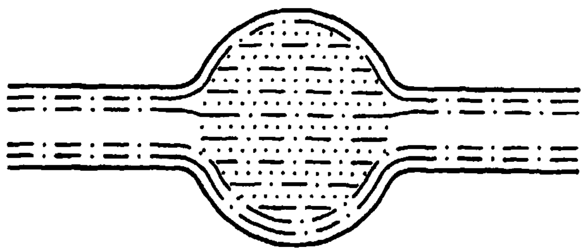

Fig. 6

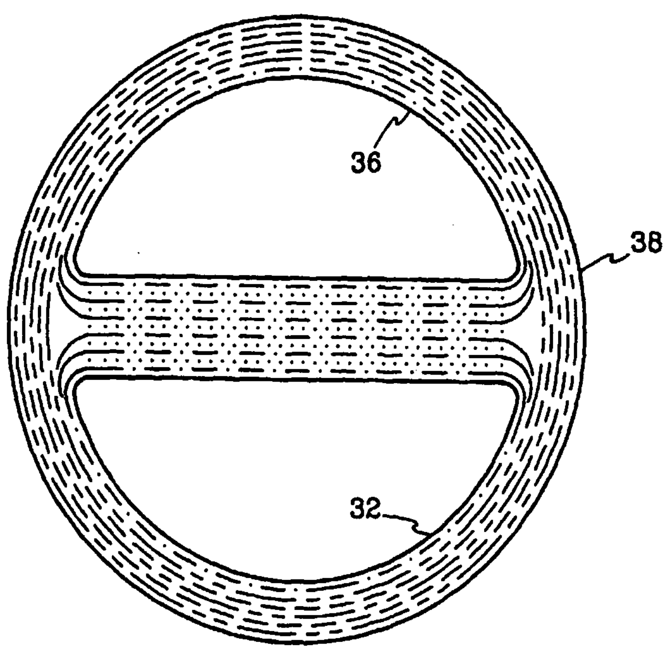

Fig. 7